FEATURE ARTICLE

Stephen Holland

Low-Cost Software Bell-202 Modem

Imagine this: rapid and reliable data processing via a low-cost software modem. With the 50-MIPS Scenix SX MCU, Stephen designed just such a modem, and it offers the ease of flash memory and in-system debugging.

In every ATM, point-of-sale terminal, and automated gas pump there's an embedded modem whose only purpose is sending and receiving identity-verification data and purchase information. These are typical of a broad range of applications in which "data communications" doesn't mean transmitting huge pdf files or other attachments between PCs.

Instead, embedded modems for information processing need to connect rapidly and reliably as well as be able to transmit and receive relatively small amounts of data at a rate that a person standing in front of an ATM perceives as fast. For this, low-speed (1200 and 2400 bps) Bell-202- and 212-compatible modems are adequate.

Because embedded modems are often used in places that require small size and low cost, designers must get a least-cost implementation that is as close to a single-chip solution as possible. An attractive solution would be one relatively cheap MCU with all the modem functions inside, eliminating everything except a serial connection and the digital access arrangement (DAA) for the telephone line.

But, this solution wasn't available until recently. Embedded modem designers typically had to go with either a multichip implementation consisting of an inexpensive 8-bit MCU and an external modem chip, or move up the complexity and cost curve to 16- and 32-bit MCUs and DSPs that avoid the silicon penalties by handling the modem functions in software.

There's an 8-bit MCU that performs the types of modem functions needed by the vast majority of embedded applications in software. Using a Scenix Semiconductor SX series MCU, I put together a circuit that, in a form factor smaller than 2" × 3", provides all the basic functionality of a Bell-202 modem, including FSK generation and detection and DTMF generation and detection.

The key to the design is that software modules, or "virtual peripherals," for each function are loaded into a fast (10-ns access time) on-chip flash program memory and executed as needed. This eliminates external modem and memory chips and additional internal silicon development, and results in an extremely cost-effective implementation. In fact, the entire bill of materials totals right around $7.

MCU ARCHITECTURE

For an 8-bit MCU to do what the 16- and 32-bit MCUs do, it needs many of the same architectural features, including a streamlined, four-stage RISC-like pipelined architecture to minimize code size and maximize performance.

Coupled with extremely fast on-chip instruction and data memory, this arrangement permits every instruction to be executed in a single clock cycle. A 50-MHz clock can provide an instruction throughput rate of 50 MIPS, and a 100-MHz clock gives 100 MIPS.

Another requirement is a deterministic interrupt-response capability that services interrupts in a small and precise number of cycles every time. With older architectures, tasks are only interrupted at instruction boundaries, so the number of cycles required to respond to an interrupt is unpredictable.

This setup not only produces slow interrupt responses but also introduces jitter into the system timing, which limits performance and accuracy. Short

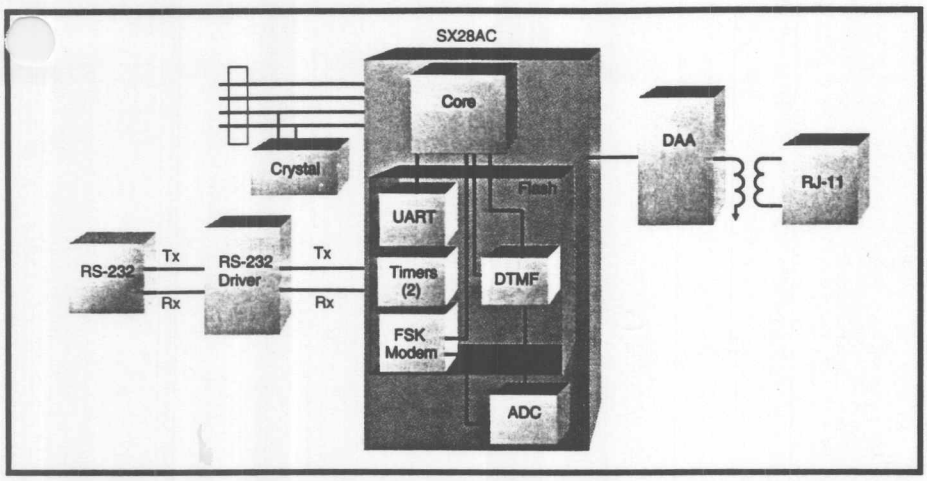

Figure 1—*A full-featured modem can be implemented with the SX28AC 8-bit MCU. The combination of high-speed MCU and software peripheral functions results in an extremely compact and cost-effective implementation.*

predictable interrupt-response times, with critical registers automatically stored in special hardware stacks during an interrupt, eliminate the problem of jitter and ensure proper execution of virtual peripheral functions.

AT THE BLOCK LEVEL

The modem design in Figure 1 uses the Scenix SX28AC, which runs at up to 50 MHz and has a 50-MIPS data throughput rate. Although the design accommodates connecting to a PC via an RS-232 connector, it can be changed to some other type of serial interface.

The modem functions can be downloaded from the Scenix web site as virtual peripherals and stored in the on-chip program memory. The virtual peripherals used in this design are:

- two 16-bit timers—one for the power-on LED and one for FSK and DTMF tone duration
- DTMF detection
- FSK detection via on-chip hardware comparator
- DTMF generation
- FSK generation
- UART (1200 bps to 115.2 kbps)

Additional features like caller ID, voice recognition, LCD drive, and numerous types of I/O can be added by downloading the appropriate virtual peripheral into the program memory.

To achieve the lowest implementation cost, the design uses a component (rather than a module) approach for connecting to the external world. For example, the cost of a DAA module is typically about $4. But, a 1200-bps modem doesn't need the sophisticated DAC, compression and decompression, and other functions performed by a DAA module.

Instead, as you see from Figure 2, I used a configuration based on opto-isolators and a transformer to provide coupling to the telephone network, which complies with the Bell-202 standard and makes the cost of the components significantly less than that of a DAA module.

DTMF AND FSK DETECTION

Connection with the telephone network is controlled by the Ring and Hook signals, which are passed through optoisolators U5 and U6 to either establish or break the connection.

When the connection is made, data received from the network is coupled

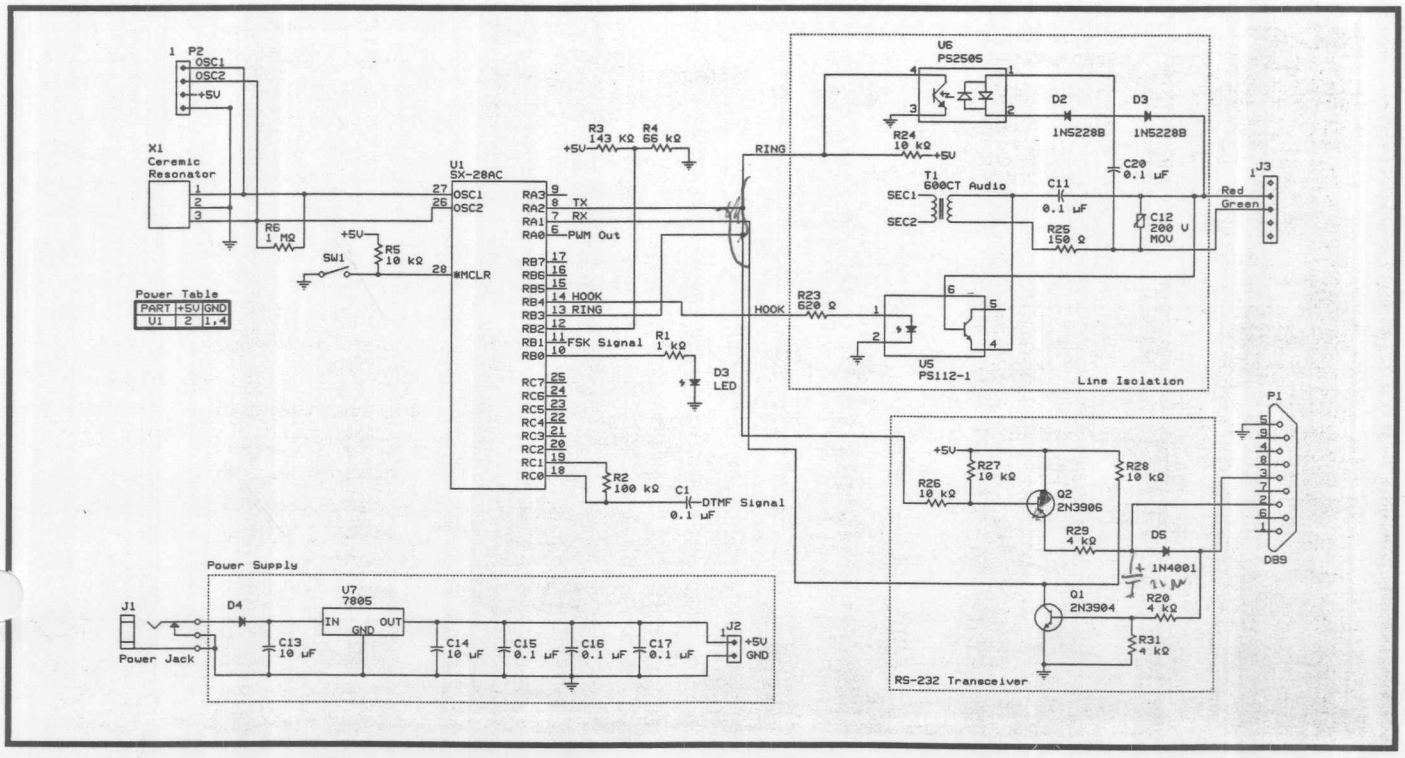

Figure 2—*Using discrete components rather than sophisticated modules for the DAA and RS-232C interfaces dramatically decreases the modem bill of materials. At 1200 bps, this configuration meets the Bell-202 standard.*

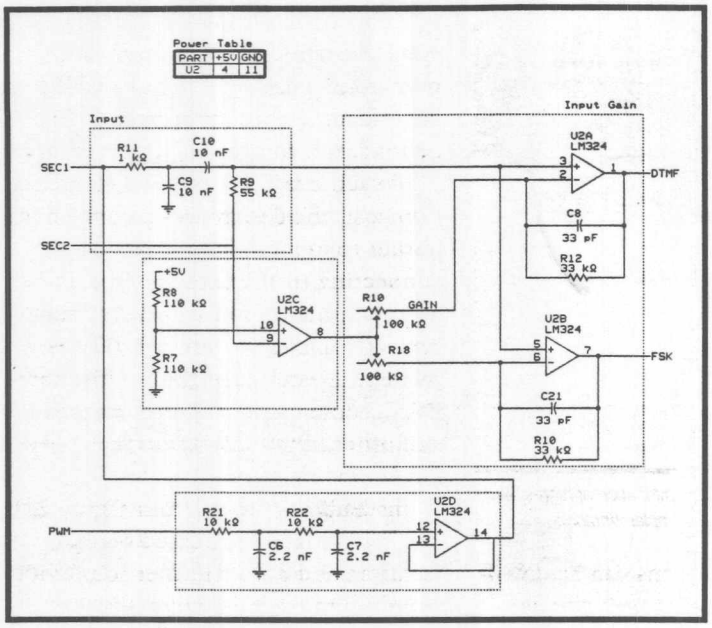

Figure 3—*The op-amp splits the DTMF and FSK portions of the single input stream. It also shifts the DC offset of the PWM output to meet telephone network requirements.*

through audio transformer T1, as well as input filter and DC offset circuit to an operational amplifier, U2 (see Figure 3). The op-amp splits the single bitstream of the input into separate DTMF and FSK signals and applies them to the MCU, where they are converted from analog to digital and processed.

The DTMF signal is applied to pins RC0 and RC1 of the SX28AC. The MCU converts this from analog to digital by sampling it in software using a digital form of the Geortzel discrete Fourier transform (DFT) algorithm. Eight separate DFTs, each with an accuracy of greater than ±1%, simultaneously sample the signal looking for the row and column frequencies that identify digits within the DTMF matrix.

To be properly selective on the target frequencies, a performance level of at least 50 MIPS is required; the sine and cosine reference signals for each DFT operation are being generated in software within the interrupt service routine to enable multiple virtual peripherals to run in parallel. A clock frequency of at least 50 MHz is required to give the DFT accuracy better than the required DTMF specification of ±1.5% (i.e., the higher the clock rate, the better the accuracy).

The same DFT technique would be possible at a much lower MIPS rate, but at the sacrifice of needing to be executed in straight-line code to maintain accuracy. Additionally, the standard for the DTMF tone duration lets it be as short as 48 ms, which the SX28AC can easily handle.

The current DTMF algorithm can detect tones as short as 14 ms. By contrast, most other 8-bit MCU implementations need at least 150 ms to detect the tone because of the straight-line nature of the code.

The FSK signal from the op-amp is applied to pin RB1 of the SX28AC. Detecting the FSK data (1200 Hz representing a logic 1, and 2200 Hz representing a logic 0) and its conversion to a digital format is done by an on-chip hardware comparator and a reference level set by an external resistor voltage divider (R3, R4) using a form of zero-crossing detection. The comparator is one of the basic sets of silicon peripherals included in the SX28AC.

The digital DTMF and FSK data is processed by the software UART and transmitted to a PC through a simple implementation of an RS-232 interface. Because the connection to the PC isn't meant to be over a long distance, a two-transistor (Q1, Q2) circuit operating at 5 V rather than the more-typical 9 V is sufficient to drive the line.

DTMF AND FSK GENERATION

Digital data received from the PC through the RS-232 interface and software UART is converted to analog signals for transmission over the telephone network using PWM techniques.

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To minimize I/O pin usage, a single PWM output pin is used. This arrangement is possible even for the two DTMF tones because the SX28AC sums the DTMF signals internally to create a single signal.

To ensure the smooth frequency shifts that are required by the Bell-202 specification, all the FSK shifts are phase-coherent. Although this requirement is easily accomplished in hardware, it requires a level of processing power only available in the SX series to work in software.

The PWM output of the MCU is applied to the op-amp, where its DC offset is moved to accommodate the needs of the telephone network. The result is applied to the acoustic transformer and on to the network.

Even though it provides all the functionality of a complete 1200-bps modem, this design uses only nine of the 20 I/O pins available with the SX28AC MCU.

It also doesn't use all of the device's 50 MIPS of processing power. This setup makes it easy to add features like an LCD interface, motor controller, or I²C-to-EPROM interface by loading the appropriate virtual peripherals into the on-chip memory and using the extra I/O pins.

APPLICATION DEVELOPMENT

Adding functions to an SX28AC-based design is as simple as going to a web site and downloading the desired virtual peripherals. New software

Listing 1—*Developing the Bell 202-compatible modem program was simplified by using an Edit window on a PC. This code describes the initialization sequence for the design.*

```
reset_entry
        mov     m,#$0f
        mov      ra,#%0110      ;init ra
        mov     !ra,#%0010      ;ra0-1 = input,ra2-3 = output
        mov      rb,#%00000000  ;init rb
        mov     !rb,#%00001110  ;rb1-3 = input,rb0,rb4-7 = output
        mov      rc,#%00000000  ;init rc
        mov     !rc,#%11111101  ;rc0,rc2-7 = input,rc1 = output
        mov     m,#$0d          ;make rc0 cmos-level
        mov     !rc,#%11111110
        clr     fsr             ;reset all ram banks
:loop   setb    fsr.4
        clr     ind
        ijnz    fsr,:loop
        bank    dtmf_gen        ;Initialize variables
        mov     delay,#23
        clr     flags
        mov     !option,#%00011111
                                ;enable wreg and rtcc interrupt
        jmp     @main           ;Jump to main code
        ...
```


Virtual Instrumentation

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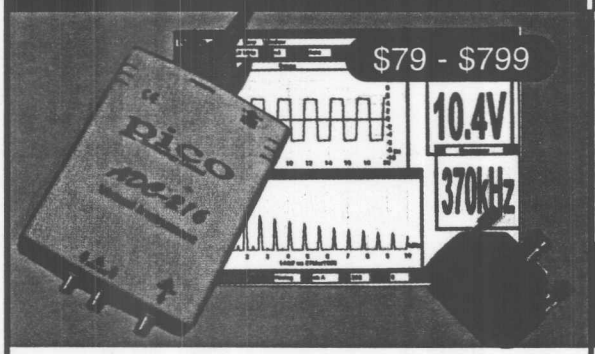

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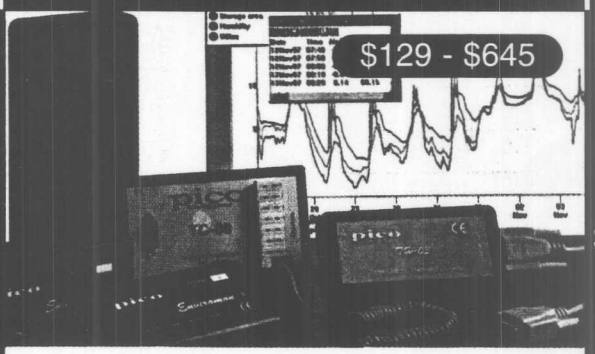

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over its oscillator pins (26, 27) using the SX-Key development system (a 0.5" × 1.5" module that connects at one end to a PC by a standard DE-9 connector and at the other end to the system board by a four-pin header interface connector). The SX-Key software, which includes an editor, programmer, and debugger, can be installed on a PC and run under Windows.

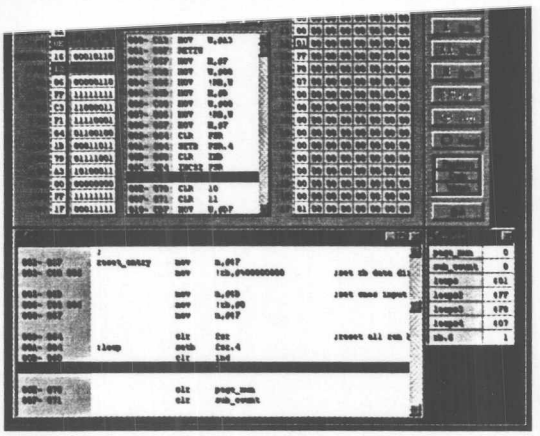

Photo 1—*The Debug window of the SX-Key development system provides visibility into the contents of all device registers, allowing individual bits to be changed as necessary.*

With the SX-Key software loaded and the PC connected to the circuit through the hardware module, software development begins immediately. The first screen is a device setup window.

It lets you set parameters such as the number of pins and on-chip memory size of the SX-series MCU you're using, the clock source (an external frequency generator in this design, although a range of internal oscillator frequencies can also be selected), and additional options like stack extensions and an on-chip watchdog timer. A configuration window lets you select the desired communication port and specify the erase and program times for the flash program memory.

With the chip parameters established, an Edit window lets you write the program. All timing-dependent needs to be written using an interrup indicator.

An on-chip hardware timer produce a real-time clock/counter (RTCC) signal that generates interrupts. The RTCC can be set to establish how many clock cycles occur before an interrupt must be serviced.

The general program flow is:

```
(load RTCC countdown)
run application code
RTCC times out, issues interrupt
  interrupt service routine
    run peripheral routine
  load RTCC countdown
  RETI (return from interrupt)
run application code
```

Listing 1 shows the initialization part of the program for this modem design.

After resetting the SX chip, the I/O ports and the default values for some software variables must be initialized. The final line of code in the reset entry code typically loads the Option

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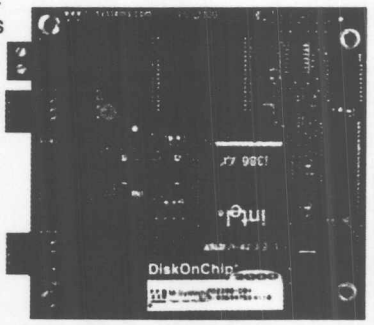

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gister with the proper value to enable RTCC clock rate and interrupts.

In this design, the contents of the RTCC are incremented each clock cycle. If the RTCC overflows, an interrupt request follows. The RTCC overflow interrupt is essential to the virtual-peripheral concept, as it provides a jitter-free time base that is used as the time slice for the peripherals. Much like an RTOS, this master clock can then increment other clocks specific to each task.

The completed program and the virtual peripherals are loaded into the MCU's on-chip program memory through the SX-Key module. A Debug window (see Photo 1) displays the result of programming the chip and provides interactive debugging options.

The left column shows the contents of registers 00–0F of the selected RAM bank in hex and binary numbers. The contents of registers 10–1F of the remaining RAM banks are displayed on the right side.

In the middle of the Debug window, the contents of the M and W registers are shown as well as interrupt and skip flags. Beneath that is listed the address, opcode, and assembler mnemonic of the selected part of the program memory.

Buttons for emulation functions are arranged across the window bottom:

- step—executes one instruction
- walk—executes multiple instructions, one at a time
- run—executes instructions at full speed
- stop—halts execution of a walk or run operation
- reset—resets the MCU
- exit—closes the Debug window

To debug the program, just reset the contents of any of the registers. All the changed registers are marked with red during debugging so you don't lose the track of what you're doing.

When you're satisfied that you've corrected the bugs, reprogram the chip. Because you're working with flash memory, you can go through as many iterations as you want to get it right.

AT LAST, A CHOICE

tion of

For about $7, I was able to de compact fully functional embedded modem that meets the needs of all kinds of applications. It was possible because designers have a choice not only of modems, but also of every imaginable type of embedded system.

Stephen Holland is a senior applications engineer at Scenix Semiconductor. Before joining Scenix in early 1998, he worked for over six years in the electronics and computer industries in Canada and Hong Kong. You may reach him at stephen.holland@scenix.com.

SOFTWARE

Software for this article is available via the Circuit Cellar web site.

SOURCE

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READER I/O

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Promise me (and the rest of us) more articles on robotics and the circuits used to interface them with the real world. "Electronic Odor Perception" by Silvio Tresoldi (*Circuit Cellar* 108) is outstanding and really helped me in my efforts to learn, develop, and have fun with mobile robots.

Would it be too much to ask for some articles dealing with software that controls robots? For example, some information on using encoders and how to actually make them work or how to use compilers and C/C++ to create hex files to be downloaded to microcontrollers.

If I continue to see issues like this, you will have a reader for life! Thank you for not forgetting the robotics crowd. Keep up the fine articles.

David Jackson
Pomona, California

FORGOT ONE

"Embedded OSs for Internet Appliances" by David Brooks in *Circuit Cellar* 107 was an extremely informative analysis of the Internet-appliance market. However, the discussion of available operating systems for embedded devices excluded one.

A company called e.Digital has developed a flash-memory file management system called the MicroOS. This file management system implements a small footprint in a digital device and it provides scalable functionality for editing and file management. The MicroOS is particularly suitable for applications involving dictation, voice, image, video and CD quality music.

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The MicroOS is an architecture-independent OS, which means it can recognize and play a range of secure audio formats while reducing product development time. The MicroOS features a reduced chip count resulting in lower cost and power requirements for digital-device OEMs. For more information, visit www.edig.com.

James LaBoda
jimee11@hotmail.com

SETTING THINGS STRAIGHT

*Editor's note: A special thanks to Richard Johnson and Dale Yarker who pointed out some errors in Figure 2 of the "Low-Cost Software Bell-202 Modem" article (*Circuit Cellar *107).*

***[1]** The TX signal is shorted to the RING signal. **[2]** In the "RS-232 Transceiver" section, Q2 has its emitter and collector reversed. The emitter should connect to +5V. **[3]** Pin 2 of P1 connects to Q2's collector (after Q2 is corrected) and not at the diode as shown.*

Richard also suggested hooking up a large cap (22 µF) from the junction of R29 and D5 to ground to help the circuit's performance.

Dale commented that if the device won't go off-hook, the polarity of the line probably reversed somewhere between the telco and J3. To correct the problem, simply reverse the green and red wires. Other ways of making the hook switch insensitive to polarity would increase the parts count too much.

The updated code, an app note that includes a corrected schematic, and some information about licensing the DTMF code is now posted on the Circuit Cellar *web site.*

*Editor's note: Although there was no mention in the "Turn the Page" article (*Circuit Cellar *108) that code would be made available, the software for Ingo's pager project is now available for download via the* Circuit Cellar *web site.*

*Editor's note: In "Astronomical Issues" (*Circuit Cellar *108), Ingo mentioned a "freely available PCB layout program," but the URL was left out of the Sources section at the end of the article. Go to ftp.linuxppc.org/linuxppc/users/harry/PCB/ to download the software.*